NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
INVENTIONS AND CONTRIBUTIONS BOARD
SPACE ACT AWARD APPLICATION

BACKGROUND:

THE NASA SPACE ACT MONETARY AWARDS PROGRAM FOR SIGNIFICANT SCIENTIFIC AND TECHNICAL CONTRIBUTIONS

The objectives of this program are to provide official recognition of, and to grant equitable monetary awards for those inventions and other scientific and technical contributions that have helped to achieve NASA's aeronautical, commercialization, and space goals; and to stimulate and encourage the creation and reporting of similar contributions in the future. To accomplish these objectives, the Inventions and Contributions Board is authorized to recommend the granting of monetary awards in amounts up to $100,000 in accordance with the provisions of the National Aeronautics and Space Act of 1958, and to grant monetary awards in amounts up to $10,000 in accordance with the provisions of the Government Employees Incentive Awards Act of 1954. Space Act awards can be made to any person with no restriction as to employer, and in accordance with the regulations as specified in the Federal Register Vol. 55, No. 5, (14 CFR Part 1240). Awards made under the authority of the Incentive Awards Act can be made to U.S. Government employees only.

GUIDELINES:

In determining the merits of an invention or a contribution, the Board depends primarily on the information provided by the contributor(s)/technical evaluator in the Space Act Award Application. Furthermore, the Board recognizes that NASA technical personnel are the best sources of reliable information concerning contributions made by employees of NASA or by employees of NASA's contractors whose activities are under their cognizance. For this contribution, it is appropriate for the contributor(s)/ technical evaluator to supply the information that the Board requires in order to make a recommendation that is equitable to both the contributor(s) and NASA. We are therefore asking you to assist the Board by completing, accurately and thoroughly, the application which follows these explanatory remarks. For your convenience we suggest that you familiarize yourself with the contents of the application by reading it completely before answering the questions. Please provide all pertinent facts, specific details, explanations, and opinions regarding seven important factors that characterize the contribution. These factors are: (1) Description, (2) Significance, (3) Stage of Development, (4) Use, (5) Creativity, (6) Recognition and (7) Tangible Value. The Board welcomes any additional information that you believe will contribute to the completeness of its deliberations. If you find it necessary to modify or expand the format of the application in order to provide such extra information, please do so.

REQUIRED DOCUMENTATION AND AWARDS LIAISON OFFICE RESPONSIBILITY:

Please be thorough and candid with your evaluation. Each section must be filled in, and where appropriate, signed by the evaluators. **In no case should the evaluator be identified as a contributor**.. The full legal name, home address and social security number for each contributor is mandatory and at least one NASA official must sign in Section II to attest to NASA's sponsorship, adoption, support or use of the contribution. If any supplementary materials are provided; e.g., additional sheets, technical papers, engineering drawings, videotape, audio cassettes, photographs, computer diskettes, etc., each must be marked and identified by the NASA Case Number. The names and contact information for individuals familiar with the contribution would be helpful for evaluation. The Awards Liaison Officer of the NASA Center where the contribution is supported is responsible for accepting the application and subsequent submission to the Board. Please ensure that the contributors have signed a Privacy Act statement such as that forwarded to the Awards Offices by the ICB on May 13, 1992. All contributions should be officially reported to NASA by submission of Form 1679 Disclosure of Invention and New Technology (Including Software).

The Board sincerely appreciates the time and effort you will devote to the completion of the Space Act Award Application. We pledge to take prompt action to review and process your application. It is our intent to expeditiously reward excellence.

NASA FORM 1329	Inventions and Contributions Board *Space Act Award Application*	NASA Case Number: ARC-14776/MACS	Date: 2006/04/06
SECTION I *SPACE ACT AWARD APPLICATION*			
TITLE MACS: Multi Aircraft Control System (supplemented with ADRS: Aeronautical Datalink and Radar Simulator)			

1. DESCRIPTION.

a. *Briefly describe the contribution. In addition, if peer-reviewed publications by contributors have been accepted on this topic in refereed journals or for refereed conference papers, please attach a copy with this form as a supplement.*

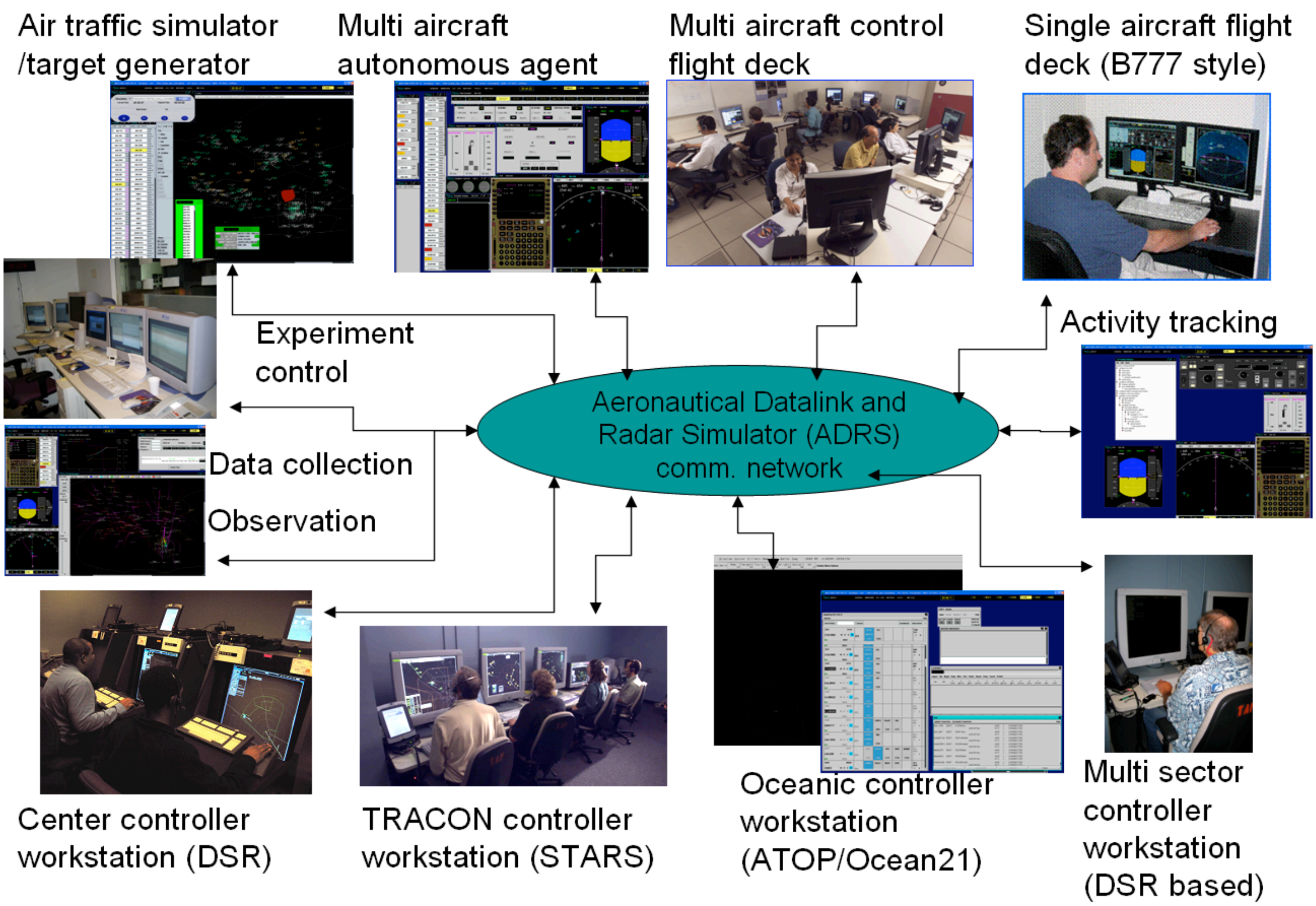
The Multi Aircraft Control System (MACS) with its networking supplement Aeronautical Datalink and Radar Simulator (ADRS) represents arguably the world's most capable, versatile, and cost-effective environment for rapid prototyping, controller and pilot-in-the-loop simulation, and evaluation of current and future air/ground operations for the National Airspace System. The existing suite of capabilities allows researchers to configure a wide range of air traffic environments, from accurately emulating current day operations to simulating many of the operations envisioned for the Next Generation Air Transportation System (NGATS) as well as the transitional stages between now and then. In order to evaluate envisioned operational environments an unlimited number of MACS operator stations can be configured and connected via the ADRS networking infrastructure. These operator stations include high fidelity air traffic controller workstations in the oceanic, enroute and terminal domains, medium fidelity "glass cockpit" flight decks for confederate pilots and flight crew participants, as well as experimenter, observer, and analyst stations. The MACS built-in scenario and target generation capabilities can be used to generate and run rich traffic problems tailored to specific challenges such as high volume, weather, and various aircraft equipage levels that are designed to excite specific properties of the envisioned air traffic environment. The integrated comprehensive and flexible data collection system enables data analysis of all quantitative measures of interest.

The primary use of the MACS/ADRS software is for evaluating future air traffic operational concepts. A simulation consisting of MACS and ADRS software represents a comprehensive test environment for experiments focusing on air traffic control operations, controller/automation integration and air/ground integration issues covering regional airspace problems, such as individual areas within Air Route Traffic Control Centers (ARTCCs) and Terminal Radar Approach Control TRACON. Some experiments require additional high fidelity pilot workstations or flight deck capabilities, such as full mission flight simulators or experimental cockpit displays of traffic information (CDTI), some cover additional domains, like airport surface and tower operations or NAS-wide traffic management. In any of the cases the ADRS provides connectivity to other simulation environments. CDTI's can be plugged into a MACS flight deck, full mission simulators can take over individual aircraft, other airspace simulations can feed parts or all of the traffic into MACS/ADRS. When connected the MACS/ADRS based simulation acts in concert with all other simulators, being able to interact, take over and release control of any aircraft at any time.

New functions that are to be tested to become integral parts of the MACS operator stations can easily be prototyped and integrated, because MACS was designed for rapid prototyping. All functions available in large scale simulations are also available in standalone instantiations running on state of the art single station commodity computers, like Personal Computers or laptops. The underlying software architecture and the JAVA programming language were deliberately chosen to give developers and researchers a platform for rapid integration and testing of advanced functions. NASA's "Smart-Skies" project for educational usage with middle school students has demonstrated that even college students were able to use MACS for rapid prototyping as indicated by a note from Greg Condon (Condon, 2006) "*MACS was a great tool to use for this prototyping. Several college students with no previous experience were able to develop several prototype capabilities and interfaces that we fine tuned to the final configuration*."

The MACS/ADRS capabilities have already been crucial to NASA's aeronautics mission to transform the nation's air transportation system and are a key asset to expediting research that is critical for addressing the needs of the Next Generation Air Transportation System a primary objective of NASA's Aeronautics Mission Directorate (ARMD). In the past, the system was a critical element in NASA's Advanced Air Transportation Technologies Project (AATT) that received a NASA honor award in 2005. It was used to rapidly prototype and evaluate several concept elements of distributed air/ground traffic management (DAG-TM) operations. Many DAG-TM research requirements are very similar to the kinds of capabilities envisioned by the Joint Planning and Development Office (JPDO) for the NGATS: Revolutionary air traffic concepts with new roles and responsibilities for pilots and controllers and highly automated systems.

When the DAG-TM research went into the prototyping phase in 2001, it became apparent that, none of the existing systems would be able to simulate and analyze the conceptualized far-term operations at a fidelity level required for a realistic assessment. Air traffic control workstations and flight deck simulators/target generators were either high-fidelity and hardly expandable with new automated functions or low fidelity, and would have still taken significant effort to be supplemented with new functions. None of the existing systems provided a suitable environment for simulating the entire air/ground infrastructure. In an ambitious undertaking the MACS development started from scratch to create a permanent solution to address the fidelity requirements and the anticipated rapid prototyping needs for the growing far-term research demand. The approach was to accurately emulate high fidelity controller workstations, state of the art aircraft capabilities and flight deck controls for all aircraft in a scenario (1 – 1000s) and at the same time prototype the envisioned ground-side automation, controller display modifications, flight management system modifications, and air ground integration capabilities. Advanced flight deck displays, conflict resolution algorithms and higher fidelity aircraft models were already available or the primary focus of other research. Therefore, connectivity to integrate these systems seamlessly into the MACS/ADRS simulation whenever necessary was provided, instead of duplicating work that was already underway.



Many different MACS operator stations communicate via the ADRS during a simulation

DAG-TM research with MACS and ADRS resulted in several awards and many scientific papers:
In 2004 a joint Ames/Langley simulation of mixed operations with controller-managed and self-separating aircraft connected up to 38 MACS operator stations at NASA Ames to the air traffic operations laboratory (ATOL) at NASA Langley and the advanced concepts flight simulator (ACFS) at NASA Ames. The joint Ames/Langley simulation team received a NASA Ames honor award and a NASA honor award. A scientific paper on the ground-side results that were gathered during this simulation with air traffic specialists working the prototyped MACS controller workstations received the best paper award at the Digital Avionics Systems Conference in Washington, DC. The paper "Impact of Free Maneuvering Aircraft on Ground-Side Operations in Mixed Airspace" by Paul Lee, Thomas Prevot, Joey Mercer, Nancy Smith, and Everett Palmer received Best of Track for Human Factors and Best of Session for Assessing the Impact of Tools and Strategies on the ATC

Environment in 2005.
In another DAG-TM study the MACS/ADRS system was configured with additional CDTIs, connected to a full mission simulator and was used to simulate TRACON operations with airborne spacing and merging in two parallel “Worlds” running TRACON operations simultaneously with air traffic control specialists and airline pilots. A paper presenting the results, titled "Air and Ground Simulation of Terminal-Area FMS Arrivals with Airborne Spacing and Merging" by Todd Callantine, Paul Lee, Joey Mercer, Thomas Prevot, and Everett Palmer, received Best of Track for Air Ground Cooperation at the prestigious 6^{th} USA/Europe R&D research seminar (ATM 2005) in Baltimore.

While the MACS/ADRS development team primarily focused on DAG-TM research, the software was provided “as-is” to other projects. Dave Williams at NASA Langley Research Center describes the use of MACS and ADRS for the Quiet Aircraft Technology project as follows (Williams, 2006): “*The ADRS software was used to provide the data connection between a piloted high-fidelity flight simulator (the Langley B757 Cockpit Motion Facility) and air traffic provided by the Langley FMS-Autoflight Simulation Tools for Windows (FASTWIN) program reading a pre-recorded traffic file… … The MACS software was used to provide an Air Traffic Control (ATC) display of the traffic, including the aircraft flown by the pilot test subjects, for use by a live ATC controller for issuing scripted communication with the test subjects. … .. The use of ADRS and MACS in these experiments resulted in a considerable savings in both time and resources for the QAT project.”*

At present the MACS/ADRS software offers many different operator stations with many advanced capabilities. These operator stations include the only high fidelity emulation of the FAA’s new oceanic system ATOP/Ocean21 and the only completely programmable and configurable high fidelity Display System Replacement (DSR) emulation of a Center controller workstation. This accurate emulation of the new MACS controller stations eliminates the previously required controller training time of several days for basic functions. Many of the simulation artifacts that frequently overshadow human-in-the-loop air traffic research are no longer an issue. The ground side automation includes highly responsive and well-integrated controller tools for trajectory planning and exchange, medium-term conflict probing logic, Advanced Airspace Concept conflict resolution logic, scheduling and sequencing traffic management automation and automatic functions for transfer of control and communication as well as required times of arrival. The flight deck capabilities include a unique, realistic, but modifiable Flight Management System as well as advanced Required Time of Arrival capabilities and self-spacing logic. Data link communication is simulated at many different levels, air/ground air/air, ground/ground and agent support is integrated for activity tracking or autonomous execution of various functions.

Rapidly prototyping new functions on top of the built in toolset in MACS opens new horizons in air/ground human-in-the-loop research. The Federal Aviation Administration (FAA) recognized this potential. When faced with the need to assess the impact of specific organizational changes in air traffic control facilities, they evaluated a number of possible simulation facilities, including the FAA Technical Center and the Eurocontrol Experimental Centre. The FAA chose the MACS/ADRS simulation in the Airspace Operations Laboratory at NASA Ames. With only a few months lead time and a relatively small budget, all required functions to support the new organizational structure, with previously non-existing controller positions and many new automatic functions were prototyped. A two week study using 10 air traffic control specialists was conducted. Observers from different organizations in the US and Europe, such as the FAA, MITRE CAASD, and Eurocontrol commented on the high quality of the provided research environment and the efficiency of the experiment. An email note by the Principal Investigator for the study, Dr. Kevin Corker of the San Jose State University, attested to this (Corker, 2006): *Dear Colleagues, Just a note to say what a pleasure and professional high point it has been to work with you on this simulation. The work you all have done has made this a flawless (relatively speaking) bit of empirical work. I know that the FAA and the Europeans are very impressed with your capability. It was made known that the FAA made the " best choice" in working with you all on this experiment.”*

MACS is being distributed through the Ames Technology Partnerships Division for use at other Government agencies, Universities and Industry outside NASA.
For example, the California State University Long Beach has created the Center for the Study of Advanced Aeronautic Technologies (CSAAT http://www.csulb.edu/~tstrybel/aavatmsrc/), using MACS and ADRS as their simulation platform. This laboratory is now used for education and an additional resource for addressing some of the pressing NGATS needs. Robert C. Maxson, President of CSULB wrote to the NASA Ames Center Director (Maxson 2005): “*This software (along with a generous donation of Hardware from The Boeing Company) made possible the establishment of CSULB Advanced Air Vehicle/Air Traffic Management Simulation and Research Center, a research facility for the investigation of human factors issues in advanced air traffic management concepts, air traffic and air vehicle displays, controls and operational concepts. … Your generous donation also stimulated the development of a new, interdisciplinary, Master of Science in Human Factors Degree at Cal State Long Beach. Current and future students will benefit from training on your software and will be able to develop thesis projects that were not previously possible*.”
Other universities and colleges have requested the software to create similar capabilities.

Boeing Phantom Works was among the first users of MACS and ADRS. Jack Dwyer, Associate Fellow at Phantom Works

notes (Dwyer, 2004): "*By providing their MACS and ADRS simulation software systems, they have enabled Boeing to begin to integrate UAVs and other advanced aircraft models in simulation. Their software has been essential to the progress made thus far, and NASA's continued development and support of these tools is vital to our immediate and long-term simulation goals in this growing arena of airspace research*."
Boeing Commercial Airplanes (BCA) has expressed a primary interest in MACS' extensive flight management and flight deck capabilities that are integrated into a comprehensive virtual air/ground environment. BCA has requested the software as a basis for future flight deck development that can directly address air/ground integration issues.

The FAA is investigating the potential of using MACS/ADRS to improve air traffic controller training. Faced with the pending retirement of the large number of air traffic controllers hired in the early 1980s, the FAA is currently ramping up it's capability to train new controllers. One bottleneck is the availability of air traffic control simulators at air traffic control centers. In March 2006 FAA personnel visited Ames to evaluate the possible use of the MACS software to supplement the training of new air traffic controllers. After a MACS presentation and a demonstration, the FAA's Director of En Route Operations, the Director of Safety and Operations, and the Training Manager among others agreed to start a formal assessment of the training potential of the software at air traffic control facilities.

The example driven application description above provides only some isolated snapshots of the capabilities that the two software processes MACS and ADRS provide. Additional information on MACS/ADRS is available at the following websites:

An overview of MACS is available at
http://human-factors.arc.nasa.gov/IHpersonnel/tprevot/Tom-Prevot-MACS.html

An overview of the ADRS is available at
http://human-factors.arc.nasa.gov/IHpersonnel/tprevot/Tom-Prevot-ADRS.html

A password protected internet accessible standalone demonstrator of MACS is available at
http://human-factors.arc.nasa.gov/ihi/research_groups/air-ground-integration/MacsWeb/HF/MacsWeb.html
Please contact Thomas Prevot (tprevot@mail.arc.nasa.gov) to obtain access

An introduction to the MACS' capabilities is available at
http://humanfactors.arc.nasa.gov/ihi/research_groups/air-ground-integration/MACSassistant/M_index.htm

Using MACS and ADRS within simulations has resulted in probably far more than 50 scientific publications. Below are a few selected referred publications:

Selected conference publications on MACS and ADRS:

- Prevot T (2006) The Multi Aircraft Control System MACS, presentation made to the FAA at NASA Ames Research Center, 2006, based upon presentation at AIAA 2005 conference on Modeling and Simulation Technologies, San Francisco, CA.
- Prevot T, Callantine T, Lee P, Mercer J, Palmer E and N Smith (2004) *Rapid Prototyping and Exploration of Advanced Air Traffic Concepts*. International Conference on Computational and Engineering Science, Madeira, Portugal, July 2004, Tech Science Press.
- Prevot, T., Shelden, S., Palmer, E., Johnson, W., Battiste, V., Smith, N., Callantine, T., Lee, P.U., and Mercer, J. (2003). *Distributed Air/Ground Traffic Management Simulation: Results, Progress and Plans*. Proceedings of the AIAA Modeling and Simulation Technologies Conference, AIAA-2003-5602, Austin, TX, August 2003
- Prevot, T. (2002). *Exploring the Many Perspectives of Distributed Air Traffic Management: The Multi Aircraft Control System MACS*. International Conference on Human-Computer Interaction in Aeronautics, HCI-Aero 2002, 23-25 October, MIT, Cambridge, MA..
- Prevot, T., Palmer, E. A., Smith, N., and Callantine, T. (2002). *A Multi-Fidelity Simulation Environment for Human-in-the-Loop Studies of Distributed Air Ground Traffic Management*. American Institute of Aeronautics and Astronautics Modeling and Simulation Conference and Exhibit, Monterey, CA, August, 2002.

Selected papers presenting results gathered with MACS and ADRS

- Prevot T. , Battiste V., Callantine T. Kopardekar P., Lee P., Mercer J., Palmer E., Smith N. (2005) *Integrated Air/Ground System: Trajectory-Oriented Air Traffic Operations, Data Link Communication, and Airborne Separation Assistance*. Air Traffic Control Quarterly Volume 13, Number 2 Special Issue on ASAS, pp. 201-229, (Francis Casaux Editor) (**invited paper**)
- Callantine, T., Lee, P., Mercer, J., Prevôt, T., and Palmer, E. (2006*). Air and ground simulation of terminal-area FMS arrivals with airborne spacing and merging*. Air Traffic Control Quarterly (**invited paper** to appear).
- Lee, P. U., Prevot, T., Mercer, J., Smith, N., & Palmer, E. (2006). "Impact of Free Maneuvering Aircraft on Ground-

Side Operations in Mixed Airspace, Proceedings of the Digital Avionics Systems Conferenc 2005e. (**best of track** DASC 2005)
- Callantine, T., Lee, P., Mercer, J., Prevôt, T., and Palmer, E. (2005). *Air and ground simulation of terminal-area FMS arrivals with airborne spacing and merging*. Proceedings of the 6th USA/Europe Air Traffic Management Research and Development Seminar, Baltimore, MD, June. (**best of track** ATM2005)
- Prevot T, Lee P, Smith N and E Palmer (2005) *ATC Technologies for Controller-Managed and Autonomous Flight Operations*. Proceedings of the AIAA Guidance, Navigation, and Control Conference, AIAA-2005-6043. San Francisco, CA, August 2005
- Prevot T., Callantine T, Lee P, Mercer J, Battiste V, Johnson W, Palmer E and N Smith (2005) *Co-Operative Air Traffic Management: A Technology Enabled Concept for the Next Generation Air Transportation System*. 5th USA/Europe Air Traffic management Research and Development Seminar, Baltimore, MD, June 2005
- Lee, P. U., Mercer, J. S., Martin, L., Prevot, T., Shelden, S., Verma, S , Smith, N., Battiste, V., Johnson, W., Mogford, R., & Palmer, E. (2003). *Free Maneuvering, Trajectory Negotiation, and Self-Spacing Concepts in Distributed Air-Ground Traffic Management*, Proceedings of the 5th USA/Europe Air Traffic Management Research and Development Seminar, Budapest, Hungary. (**best of track** ATM2003)

b. *In what NASA program, project or mission has this contribution been used or will be utilized and to what extent*? (*include any non-aerospace commercialization applications)*

The MACS and ADRS software has been used for many projects crucial to NASA's mission, resulting in high quality research results and significant cost-savings. The growing user community and project indicate a great potential for future use:
The following list of projects that use MACS is categorized into research, training, and education

1. Research (Rapid Prototyping and Experiments with MACS/ADRS):

Airspace Systems:
Trajectory Oriented Operations with Limited Delegation
- NASA ARC Simulation demonstrations and experiment in June 2006
- NASA/FAA/MITRE/UPS Simulation and Field Test

US Tailored Arrivals
- NASA/Boeing/United Airlines/FAA Simulation of Tailored Arrival operations (Oceanic/Enroute/TRACON)

Multi Sector Planning
- FAA/SJSU/NASA Simulations of area operations with/without multi sector planner and advanced automation

Virtual Airspace Modeling Systems
- NASA Real-time demonstration of Virtual Airspace Systems Technologies (VAST-RT)

Advanced Airspace Concept
- NASA ARC Demonstration and early implementation of AAC conflict resolution algorithms

Advanced Air Transportation Technologies:
Distributed Air/Ground Traffic Management
- NASA ARC/LaRC simulations of Concept Element 5: Free Maneuvering (2003/2004)
- NASA ARC simulations of Concept Element 6: Trajectory Negotiation (2003)
- NASA ARC Simulations for Concept Element 11: Terminal self-spacing (2004)
- NASA LaRC controller displays for Concept Element 11: Terminal self-spacing (2004)

2. Research (Simulations with mostly "MACS/ADRS as is" components)
Quiet Aircraft Technology (QAT)
- NASA LaRC Simulation infrastructure and controller displays (2004/2005)

CTAS Enroute Descent Advisor Development
- NASA ARC Simulation infrastructure and flight deck interfaces to provide flight management capabilities (2002-now)

Access 5

- NASA ARC/Boeing controller displays and flight decks for Access 5 simulations (2005)\
- NASA ARC/CSULB UAV simulations

Security

- NASA ARC Simulations with integrated flight deck and controller agents

3. Education

- NASA Smart Skies educational usage with middle school students
- CSULB/Boeing Phantom Works: Center for the Study of Advanced Aeronautic Technologies
- San Jose State University
- California State University, Northridge

4. Training (potential use, software requested)

- FAA/NASA potential use for training of developmentals in air traffic control facilities
- Dowling College training and research at pre-academy levels

5. Other users for Analysis and Technical Reference

- Northrop Grumman IT
- Sensis Corporation.
- Titan, Inc.
- Spectrum Software
- NASA North Texas facility
- ASA Ames University Affiliated ResearchCenter
- FAA Technical Center

c. *Provide details describing how the contribution works or operates relative to system, subsystem, components, etc.*

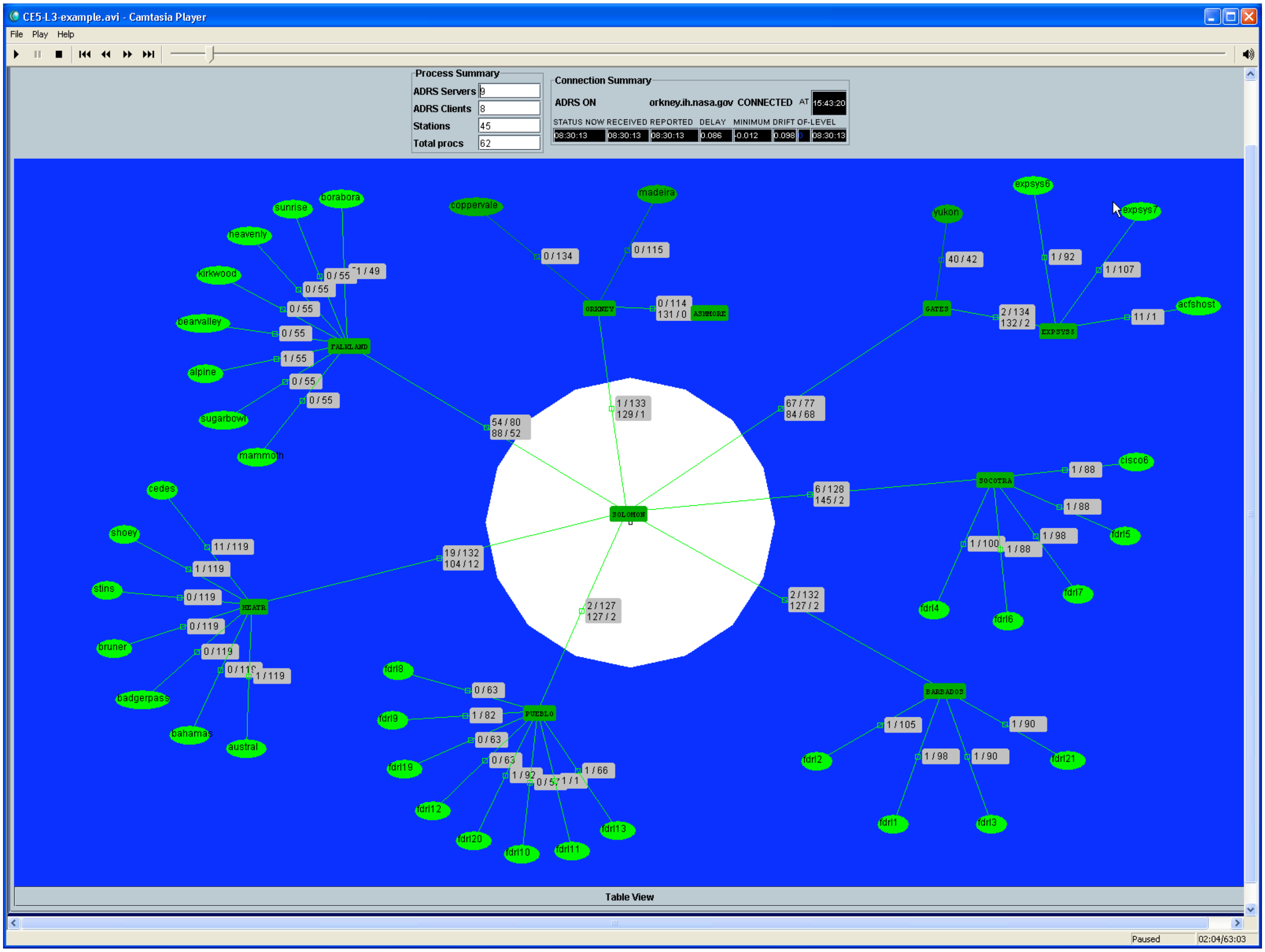
The contribution consists of two components: The Multi Aircraft Control System (MACS) provides all user interfaces and hosts the majority of the operator tools and the Aeronautical Data Link and Radar Simulator (ADRS) connects the different MACS stations and other simulation components or simulators.

ADRS

The ADRS is a software process that allows multiple heterogeneous client processes to exchange all necessary information in the same or multiple simulations. It is a C software process that can run on UNIX, WINDOWS and Mac OSX platforms and is portable. New components can either plug into the ADRS if they implement one of the different communication protocols the ADRS provides or the ADRS code can relatively easily be modified to meet the new components needs. For small simulations one ADRS process can handle all the necessary communications, larger simulations can launch a network of ADRSs. Though used in many different ways, each ADRS software program is identical. Each ADRS can serve many additional ADRS clients, which themselves can serve additional clients. There is no limit to the number of servers and clients to be included in the simulation, because adding another ADRS-node can expand each node.
All ADRSs share all required information to allow clients to connect to any node and receive the same data quality and quantity. Therefore the number of simulation hubs can be tailored to network loading and real time requirements. If for example one ADRS appears to suffer from delays because of the number of network intensive clients an additional process can be started and half of the clients can be moved to the second one. All processes communicate with the ADRS via TCP/IP socket communication and use custom protocols tailored to the individual process types. Besides communication management and data distribution the ADRS also simulates and emulates the following functions:

- Host Emulation,
- Radar Simulation,
- Data Link Simulation,
- Aircraft State and Trajectory Data Harmonization and Maintenance,
- Process Control and Health Monitoring.

A single ADRS or a network of ADRSs can be compared to an internet for air traffic simulations. Simulation components can connect to the ADRS at any time before or during a simulation. All ADRS nodes provide the same information quality. The ADRS is unique in that all information are shared between the different ADRS nodes without any particular action to be taken by the user. Clients have complete control over what data they receive and how frequently. The data interfaces work on a subscribe/response basis and are very powerful. The ADRS can provide data about precise aircraft positions and states, flight plans, four-dimensional trajectories, controller inputs, air traffic management information, simulated radar targets, aircraft guidance inputs, health status information. It can simulate ADS and CPDLC data link capabilities and convert data into formats that simulated aircraft and ground automation can understand.



Network of 9 ADRS communication processes, 8 MACS controller stations, 19 MACS pilot stations, several CDTI's, and 4 MACS data collection/observer stations, a full mission simulator, and a gateway to another simulation. This recording was made on a MACS experiment manager station at the start of a data collection run. The process view is generated in real-time based on data received from the ADRS' integrated health reporting system. ADRS processes are shown as green rectangles, operator stations or gateways as green ovals. Gray boxes show number of messages per second (in/out). Multi line boxes indicate that two sockets (server and client) exist between the processes. Clicking on each node will expand it and provide detailed process information.

In the development of the ADRS particular emphasis has been put on flexibility, speed, robustness and failure recovery. The software was designed to process all of its potentially numerous connections rapidly, store all information internally and distribute the information based on received requests and message priorities. The programm cycle is straightforward and starts with an initialization cycle, then enters a processing loop until terminated by the user, at which point the ADRS gracefully closes all its connections.. During the processing loop the ADRS first reads data from all clients and servers until the sockets are empty, or predefined timeout parameters are reached. All received information is stored in either aircraft specific records or transactions. After the read step is completed the ADRS processes the stored data as required. This processing can include simulating radar sites, adding data link delays or harmonizing information. Next the data is distributed to all connected processes according to their submitted requests and message priorities. The internal data store represents the sum of all information in an ADRS internal format. All incoming and outgoing messages are converted into the connection specific data format and byte order. These conversion functions are unique to each type of connection and therefore implemented inside the socket processing code. Many custom connections are provided to different full mission flight simulators at NASA Ames and Langley Research Centers, the Center/TRACON Automation System (CTAS), Cockpit Displays of Traffic Information, and the Pseudo Aircraft System (PAS), to name only a few. One of these custom interfaces provides a connection to the Enhanced Traffic Management System (ETMS)/Aircraft Situation Display to Industry (ASDI) data feed and therefore allows feeding quasi live traffic into all simulation components. MACS, other ADRSs and non-legacy simulations are using a more generic Multi Purpose Interface for communication to the ADRS that can make all ADRS-stored data available in a very efficient manner. Connectivity via this interface is decribed in (AOL 2003).

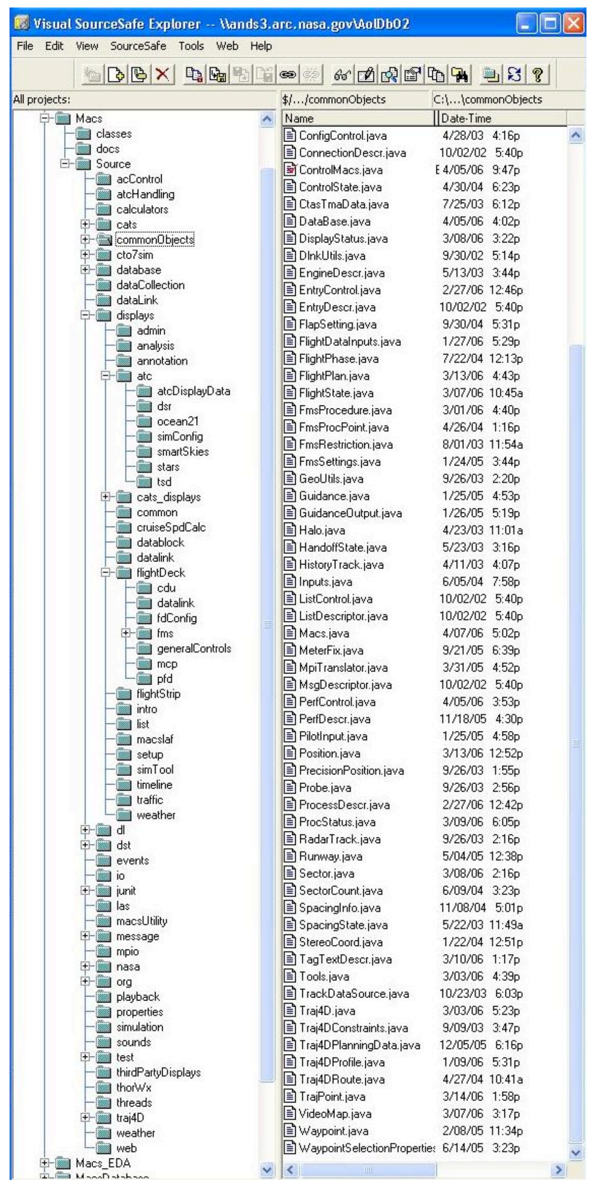
The simple, yet powerful processing scheme allows the ADRS to accept connections at any time during a simulation and immediately provides all of its stored data according to the received requests. Thus, any process that connects is updated with all relevant simulation information within seconds after connecting to the ADRS. This provides great flexibility for new processes to joining the simulation and has major positive implications on robustness and failure recovery. For example one ADRS can always serve as the backup system to the other. If a process terminates for whatever reason, it can be restarted and receive the data from its backup process. The same is true for any operator station, like all the MACS stations.
Having the option to restart any station during a running simulation with minimal data loss increases the error tolerance of the overall simulation significantly, as individual failures do no longer cause a loss of an experimental run. The communication architecture of one ADRS or a network of ADRSs has proven extremely reliable over the years in many different projects and locations, sometimes serving data on thousands of aircraft and data link transactions. This has made possible running extremely large scale simulations not just for one time demonstration purposes, but as an environment for controlled experiments, producing scientifically meaningful results.

MACS

The preceding sections of this application have indicated a wide range of capabilities and uses for MACS. The source code is organized in packages that reflect this range. MACS is a big program with more than 250,000 Lines of Code in over 1200 files. It is easy to navigate through the source code directory structure and find the implementation of specific or commonly used functions. Programmers that are not familiar with the system can typically start contributing by adding new functions or modifying existing capabilities in the first two weeks of familiarization with the system. This is the result of a deliberate design approach, which sets this software far apart from other systems that usually require extensive developer education.

The design and development of MACS was based on extensive experience in running, modifying, and integrating many different existing flight simulators, target generators, decision support tools and communication infrastructures for various research projects. In working with these existing systems, it became apparent and frustrating that many functions were missing and often very similar functions were implemented in many different, often complicated, and sometimes proprietary ways. Capabilities needed or available on one system were incompatible with the other system or had to be added to all subsystems. This made prototyping of new integrated functions difficult and very time and resource consuming.

MACS is designed for rapid prototyping. The main idea is to provide a central object oriented representation of all information available, process the information with an extensive library of commonly used methods, and provide displays and controls to view and stipulate the situation from various operator perspectives. The centrally represented data include among many others aircraft lists, weather, data link messages, aircraft performance characteristics, flight states, trajectories, flight plans, flight deck inputs and controller inputs. Commonly used classes and methods include items such as trajectory generators, conflict probing algorithms, surveillance simulators, aeronautical calculators, basic display layouts and symbols, input processing routines and communication functions.

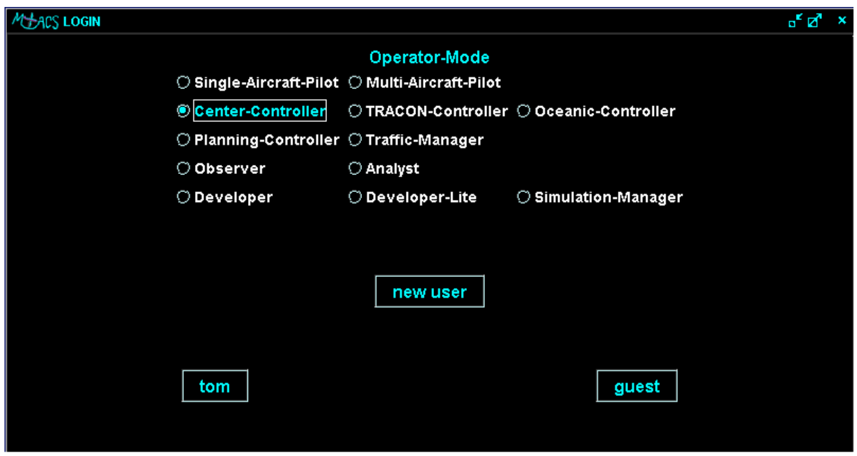


Snapshot of MACS Source Code Repertoir

Each MACS station uses exactly the same software. In fact, only one baseline version of MACS is continuously maintained and all functions are part of this version. Setup files and startup options specify which functions and information are available to each operator depending on their role in the simulation and the experimental objectives. Thus, any MACS station can be one or more of the following applications:

- An air traffic simulator
- A medium fidelity flight deck with full flight management system (FMS) capabilities
- A high fidelity air traffic controller workstation with advanced automation (Oceanic, Center , and TRACON)
- An experiment control station
- A data collection system
- A scenario generation tool
- A rapid prototyping environment for new air traffic control and management automation
- A rapid prototyping environment for flight deck automation
- An analysis tool
- A system to participate or control large scale distributed simulations with many operators
- A standalone application to assess and demonstrate new ATM concepts on any state-of the art computer

The operator mode for a given session is selected during startup and drives which displays are made available, which functions are activated and which situational knowledge can be used. The performance of the station is automatically being optimized for the specific operator mode.



MACS Operator mode selection panel

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To preserve the integrity of the information used for the various operators MACS pays specific attention to processing and displaying only that subset of situational knowledge that would realistically be available at the respective operator's position. For example, an air traffic controller today usually does not know the precise location of an aircraft, only the position estimated by the surveillance system is available. MACS provides setup functions to select the sources and accuracies of the surveillance system providing data to the controller to remain true to the current reality and at the same time enable research using more accurate position data of the future. At the same time the flight deck displays and functions use the more accurate flight state information that is realistically available on the aircraft.

MACS uses unconventional and innovative methods at many different hierarchy levels. A comprehensive description would go far beyond this application. Instead the general architecture is described as an example for the high level implementation. As an example for a low level implementation the prototype design of a function is described that was a specific human/automation interaction problem for many years: manual trajectory planning.

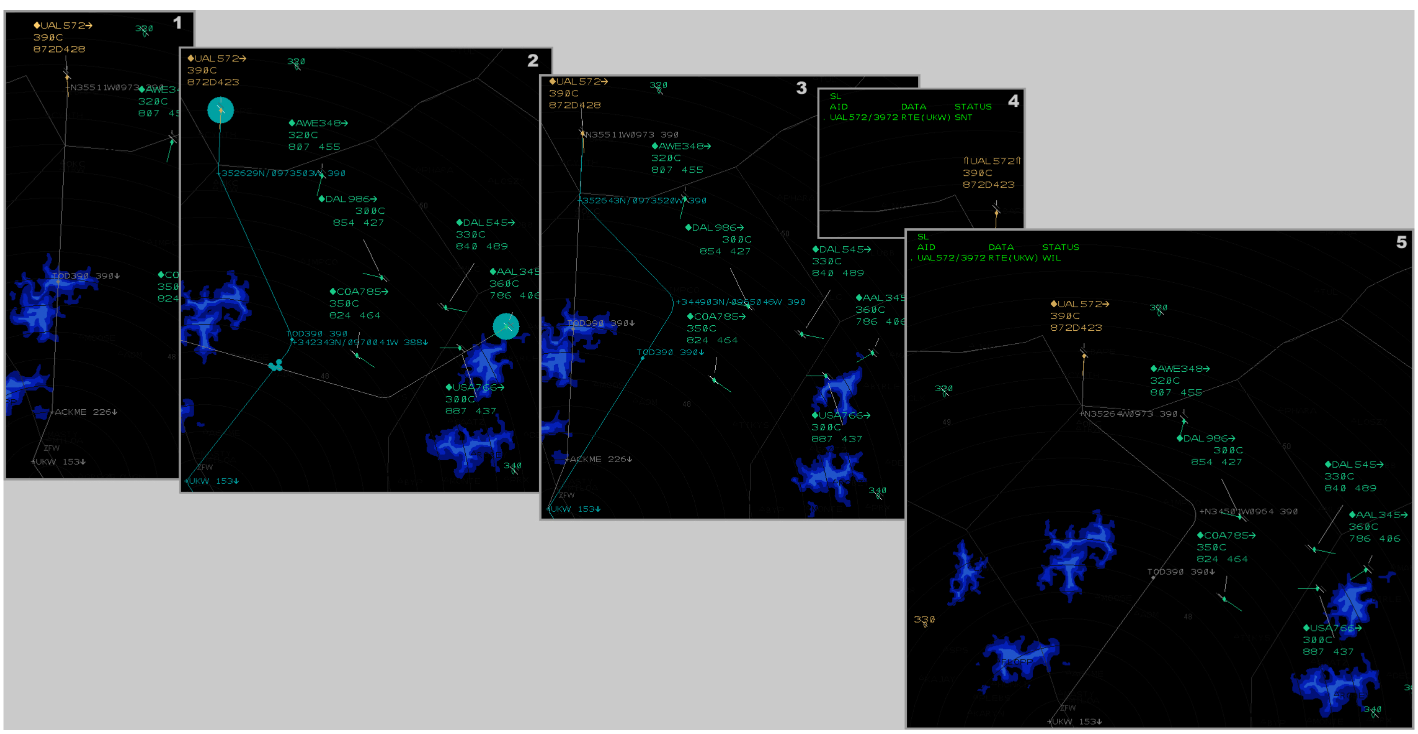
Architecture: Performance and Robustness

Because MACS is intended to be used by many different operators and for human factors experiments, three of the primary design goals of the MACS architecture were to achieve a very responsive system performance, a high level of reliability and an easily extendable system. MACS is implemented as a highly multi-threaded java application. Each functional block and each user selectable display is controlled by its own thread. A thread can be best described as a parallel process. In MACS threads are only activated if they are needed for the specific operator mode. For example, an en route air traffic controller workstation does not need to run the aircraft simulation or provide access to flight deck displays, or oceanic ATC displays. Therefore if a specific operator mode like “Center-Controller” is selected the threads enabling irrelevant functions are never started and do not cause any extra system load.

Threads that are active during a session register with a special thread observer that is tasked to check all other active threads for proper functioning and restart those that appear to have malfunctioned. This process allows the system to cope with the majority of minor failures, simply be restarting the malfunctioning thread. The system heals itself without the operator knowing it and makes for a very reliable and robust application. The run cycle times of the threads are automatically adjusted to the system loading. If excessive system load is expected, because for example an unusually high amount of aircraft has to be processed, many threads are automatically changed to be updated at a lower frequency. This helps avoid deadlocks or not keeping up with high priority tasks that could negatively impact the rest of the simulation, or the look and feel for the operator. Experimenters and Developers can monitor and adjust thread behavior via a built-in control panel. Currently, the most demanding operator mode “Developer” starts all 160 threads, the least demanding “TRACON-Controller” starts 54 threads.
Very often entirely new functions or displays need to be integrated into the system. In MACS this process is very simple, because new functions or displays can be added with only few lines of code as only a few common classes need to be extended and added to two source files. This will ensure proper window and thread management of the new functions and gives the new capabilities direct access to all data and methods publicly available inside MACS. For example an initial prototype of the Advanced Airspace Concept conflict resolution logic that had been developed in JAVA in a different platform was added to MACS in a few days and is now available for further evaluation and can be updated with new code at any time.

Prototype of highly responsive trial planning function

As a second example for MACS software specifics this section briefly describes how a specific human-automation interaction problem was addressed. For many years research had reported that manual trial planning of aircraft trajectories was unacceptable to air traffic controllers in high workload situations. Manual route trial planning means that a controller graphically changes the aircraft’s route of flight by inserting, deleting or moving points along the trajectory. During this process the new trajectory should be examined for medium-term conflicts with other aircraft. The DAG-TM research required a conflict resolution tool available for controllers to use in high workload situations. No suitable automation was available. So, the dilemma was to prototype a tool that was already deemed unacceptable.



MACS trial planning prototype integrated with data link around local storm cells

Prior acceptability assessments were based on prototypical tools that provided a relatively slow response time (up to several seconds). Controllers had commented that this slow response time was the main reason for bad usability ratings. So, the idea was to try and prototype a highly responsive trial planning tool and to determine whether this would be more usable.
A traditional trial planning implementation involves an external central trajectory generation and conflict probing engine that receives requests from all operator stations, generates the trajectories based on the provided input parameters, and examines the trajectories for conflicts. This is done by processing the trajectories of all aircraft in the conflict probe cycle.

This traditional implementation typically suffers from communication delays, depends on how fast the trajectory generator is implemented and how many aircraft have to be examined.

The MACS prototype implementation addressed these problems as follows:
Communication delays: MACS is uniquely designed to provide all functionalities internal to the operator stations and does not use an external computational engine. Therefore, the communication delay problem to the external engine is solved by design. Another communication delay may occur between the time that the controller drags the position and the trajectory manager that calls the trajectory generation and conflict probing functions are invoked. The MACS prototype addresses this problem as follows. For manual trial planning a high priority thread is used that is idle if no trial planning happens. When the thread is activated for trial planning it starts its bookkeeping task and extracts the current drag position from the display at the last moment before calling the trajectory generator. This reduces remaining delays to a minimum.
Fast Trajectory Generation: The MACS trajectory generator is implemented to use performance-based look-up tables instead of solving differential equations through integration. Furthermore, it uses an innovative profile generation scheme that is capable of generating accurate enough trajectories in only two to three iterations. This scheme is based on first estimating the trajectory values for turns, altitudes and speeds and then fitting in pre-defined individual lateral and vertical segments as applicable between the given constraints. With this trajectory generation scheme MACS can compute fairly accurate trajectories within very few milliseconds and maintain and update hundreds of trajectories (up to nine per aircraft) every few seconds within in real time. The MACS trajectories have been validated against trajectories generated by traditional system, including Flight Management Systems and are also being validated against actual flight data. The validation shows a high level of accuracy that is entirely adequate.

Conflict Probing: The third area that causes significant delays in receiving the trial planning results is the conflict probing process. Traditionally trajectories for conflict probing are either generated in the conflict probing cycle or are stored in a format that contains all trajectory points with parameters identifying the position and the estimated time at the point. A typical conflict probing algorithm to examine a specific test trajectory includes the following steps:

1. Start with a time 20 seconds from now and continue the loop for every additional 20 seconds, until the maximum look ahead time (e.g.) 20 minutes is reached.
    a. Compute the estimated position of the test aircraft along the test trajectory at the time step
    b. For each other aircraft:
        i. Compute the estimated position along the test trajectory at the time step
        ii. Compute the distance between the estimated position of the test aircraft and this position
        iii. If the distance is less than the specified minima store the conflict information
2. Compile the results of the probe

In particular step 1bi in this algorithm is very time consuming. It requires computing the position for each aircraft at every time step. To accelerate the processing the MACS conflict probing is implemented differently. MACS maintains a static array of time intervals that it uses for conflict probing and adjusts only for the progress in the simulation time. Whenever a new trajectory is computed that will be used for conflict probing, it also computes and stores all estimated positions at the predefined time-steps. When a high priority trajectory has to be examined all estimated positions are already available and only comparisons need to be made. This eliminates step 1bi entirely from the conflict probing cycle and, combined with an efficient filtering and optimization scheme, speeds up conflict probing significantly. A responsive conflict probing algorithm will be crucial to an operational implementation of the envisioned NGATS functions.

With this logic the system response to manual trajectory planning was reduced from seconds to milliseconds. This means that conflicts are indicated in real time while a controller drags the trajectory points across the screen.

This logic was used in several experiments. Unlike in earlier studies, the manual trial planner received the highest usability and usefulness ratings from air traffic control specialists. The objective data showed that this caused radar vectoring to be practically eliminated in favor of trajectory changes. Radar vectoring is a big problem for future air traffic concepts. Therefore, this effect is very desirable from an air traffic management standpoint. The functionality can now be used to drive requirements and specifications for operational systems.

The two descriptions above should be viewed as examples for innovate software design and level of detail that can be found throughout the MACS software. More information on many other aspects can be found in the referenced publications.

2. SIGNIFICANCE.

a. Explain why the contribution is significant: scientifically, technologically, or from a humanitarian viewpoint, to the aeronautics, space community, and non-aerospace commercial activities.

The current and future contributions of the MACS/ADRS software to a broad range of areas are significant for a number of

reasons. For example, the DAG-TM simulations have had a major impact on identifying benefits and issues with new roles and responsibilities of pilots and controllers in future automated air traffic management environments. Simulations on Tailored Arrivals, the Quiet Aircraft Technology program, and the ongoing research on Continuous Descent Arrivals progress operational implementation of environmentally friendly technologies.
For the future MACS and ADRS provide a highly capable platform for NASA scientists to rapidly prototype and evaluate visionary NGATS automation and operations, which directly supports key objectives of NASA's aeronautics focus, such as:

" *3. Focus research in areas that are appropriate to NASA's unique capabilities; and*
4. Directly address the needs of the Next Generation Air Transportation System (NGATS) in partnership with the Federal Aviation Administration (FAA) and other government agencies…"

At the same time, one of the main advantages of the software is its portability and the low requirements on hardware and software, which opens up a range of other potential applications. Universities like CSULB can establish low cost air traffic operations laboratories and educate students hands-on on air traffic management issues, hence provide additional research resources.
Finally, MACS and ADRS can potentially contribute significantly to addressing the FAA's controller training problem at a fraction of the cost to the tax payers that other solutions may require.

b. Estimate the degree of scientific or technological significance by a mark on the line below:

0___________1_______________2___________________3_________________4____________X_____5

None ***Modest*** ***Average*** ***Major*** ***Maximum***

c. Estimate the significance of the contribution relative to a specific NASA program or mission by marking the line below:

0___________1_______________2___________________3_________________4____________X_____5

None ***Modest*** ***Average*** ***Major*** ***Critical***

3. STAGE OF DEVELOPMENT.

Indicate the stage of development of the contribution by a mark on the line below:

0___________1_______________2___________________3_________________4____________X_____5

Concept ***Simulated*** ***Tested*** ***Fully Developed*** ***Operational***

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4. ASSESSMENT OF USE.

a. If the contribution is now in operation, describe its performance and value within both the aerospace field and its application to non-aerospace commercial and government uses.

MACS and ADRS are currently in operational use at NASA Ames and Langley Research Centers, Boeing Phantom Works, California State University Long Beach, and other Universities and research institutions. As explained in the preceding sections of this application the primary value for the NASA use lies in the rapid prototyping of advanced functions for visionary NGATS concepts and thoroughly evaluating their impact in a meaningful operational environment using the comprehensive data collection system. For non-NASA research users the application provides a low-cost/high fidelity simulation environment to conduct focused studies according to their research needs. Non-research institutions can use the simulation environment for training and education. For all these purposes MACS and ADRS perform at an extremely high level of reliability and continuously produces high quality research results. As the system was specifically designed for the air traffic operations domain non-aerospace commercial uses will require software modifications. The general simulation layout as well as the internal software structure could be applied to other simulation applications like marine or surface applications. The displays and performance characteristics would have to change accordingly.

b. If the contribution is not now in operational use, describe its most likely or previous applications and the extent of commercial,(includes non-aerospace commercialization) government and/or NASA-specific uses.

The contribution is in operational use

c. Will the contribution increase in value or in its applications over time and in what manner?

The contribution will certainly increase in its value over time, as all new functionalities are added into the same framework and hence increase the potential applications. The primary NASA application of rapidly prototyping and evaluating controller/pilot/automation interaction in NGATS operational visions is expected to lead to an even more powerful system with increased capabilities. Spin-offs like the FAA's controller training application or the flight deck development initiative at Boeing will increase the value of MACS and ADRS as a simulation capability for other users and can lead to increased cooperation between government, universities, and industry. As universities are starting to create educational programs like Master's programs around the application, the software will foster an increase in the number of college graduates that are well educated in the air traffic domain.

5. CREATIVITY.

What is your assessment of the creativity displayed in the conduct of this contribution, relative to the expected performance of those in similar positions?

*None*________*Low* __________*Modest*_________*Average*________*High*_________*Very High*______X_____

6. RECOGNITION

What forms of recognition have been received by the contributors for this contribution? Have previous awards been made to the contributor(s) for this accomplishment? Please describe.

Thomas Prevot received a Software Release Award for the Multi Aircraft Control System (MACS) in 2004. He also received a NASA Ames Honor Award as Contractor employee in 2004 that was in large part related to the development and experimental use of this system. The Joint Ames/Langley DAG-TM simulation team received a NASA Ames Honor Award and a NASA Honor Award in 2005 for a simulation that made extensive use of the MACS/ADRS simulation capabilities. Thomas Prevot was a co-author of several papers that received best paper awards for scientific results gathered with the software.

7. TANGIBLE VALUE.

As a measure of the tangible value of this contribution, estimate the following:

a. NASA cost savings to date and in future years.*

MACS and ADRS provide cost-savings on many different levels.

Development savings:

MACS and ADRS were created to rapidly prototype DAG-TM capabilities for the AATT project. Research results and prototype demonstrators were expected deliverables. The powerful new simulation and rapid prototyping environment to host the new capabilities is a bonus that was created at no additional cost. Therefore, any use beyond the DAG-TM project is a direct cost-savings. MACS and ADRS were used in other NASA projects for several years. In 2004 and 2005, at least three other NASA projects used the software for different applications as is. It can be assumed that each of these projects would have needed to support at least one or two developers for creating and maintaining a capability similar to what MACS and ADRS already did. Therefore, the development savings to NASA so far have exceeded one million dollars. With a growing user community and increased research demands, at least a similar amount can be expected annually. In addition the current capability will allow for an immediate assessment of many aspects related to NGATS operational concepts. This will allow programs to plan full mission simulations in the first year instead of building up the required capabilities for at least 2 years with at least 5 persons. This results in additional cost savings of several millions USD.

Direct savings during experiments:

High fidelity pilot and controller-in-the loop experiments using MACS and ADRS can be conducted in half the time that was previously required, because of the much shorter training period. Instead of two weeks (one week training and one week of data collection), MACS/ADRS simulations can be conducted in one week and produce high quality results. Depending on the size of the experiment this results in a savings of ten thousands of dollars per experiment.

Potential cost savings for controller training to the FAA and tax payers:

If the FAA determines that the MACS/ADRS can serve their needs as a supplementary training system in all of the 20 facilities in the US, this software, compared to commercial products, could result in installation savings on the order of 7 million dollars as estimated in the section below. It has been demonstrated that a MACS/ADRS training position will require only one "pseudo pilot" in contrast to the two required in the current and most other systems. This is a cost savings of one person per trainee.

b. Current market value and potential as a commercial product or process.

There is no air traffic simulation capability on the market that provides nearly the same range of functionality and level of fidelity as the MACS/ADRS system. Commercial simulation products with high fidelity operator stations are typically tailored to specific customers and are very expensive. Therefore, information on general pricing is hard to find. One example that can be used to get an idea is the following: BAE-Systems, offers DATS - Durable Aviation Trainer Solutions and "DATSino

– a low cost ATC training simulator" at 105,000 USD (60,000 GBP) per radar position for a single installation, and 52,000 USD (30,000 GBP) per position if 10 positions are installed (http://www.airport-int.com/categories/air-traffic-control-simulators/cits-introduces-datsino.asp). After the FAA has expressed interest in using MACS/ADRS as a training system, cost estimates have been made for a MACS/ADRS based radar training position that consists of one high fidelity position for the trainee and one position for the pseudo pilot and includes numerous additional capabilities for scenario generation, data collection and analysis. The complete hardware including the operational keyboards and trackballs for a position like that would cost approximately 15,000 USD. Both systems can run on standard PCs, MACS/ADRS also on any other platform. Assuming conservatively that the per position cost of DATS includes hardware (which is not clear from the publicly available information), a rough estimate of the market value of the MACS/ADRS software as an ATC training system lies between 90,000 USD for a single position system and 370,000 USD for a 10 position system.

c. *Other measurable value: increased efficiency, enabling technology, improved management, etc.*

One increase in efficiency can be demonstrated in that the entire MACS/ADRS development so far has been done by a small development team (on average 3 developers for 4 years). Approximately 250,000 Source Lines Of Code (SLOC) have been produced in MACS and compute to approximately 8-10 SLOC per programmer and hour, which is more than double the amount of other efficient research applications and almost 10 times the industry standard.

MACS/ADRS is clearly an enabling technology for research on NGATS operational concepts. It is also an enabling technology for generating simulation capabilities at very low cost. This can lead to new air traffic laboratories for educational and research purposes.

APPLICANT'S SIGNATURE: ____DATE:_____________

**State the rationale for the above cost estimates.*

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SECTION II COMMENTS AND CONCURRENCE

1. EVALUATOR

I recommend/do not recommend a Space Act Award for this contribution for the following reasons.

The MACS software provides a critical role in the development and evaluation of new concepts for safely increasing the capacity and efficiency of our National Airspace System. MACS allows ideas to be quickly turned into working prototypes with which designers and domain experts can directly experience how the new system can work. This capability greatly accelerates understanding and refining the critical elements of the design. The high operational fidelity of the system and the robustness of the software allow proposed systems to be experimentally tested and compared. Every person traveling by air in the Next Generation Air Transportation System will benefit from the revolution in research capability provided by Dr. Prevot's MACS software.

Printed Name and Signature	*Title*	*Date*
NASA Installation	*Contractor*	*Other*

2. EVALUATOR'S SUPERVISOR

I support/do not support a Space Act Award for this contribution for the following reasons.

I strongly support a Space Act Award for the MACS/ADRS software package. This ground-breaking capability for large scale human-in-the-loop simulations has made possible the research on operational aspects of envisioned far-term air traffic management concepts like never before. This capability enables NASA uniquely to address the complex human factors associated with controller/pilot/automation integration issues that are crucial to the implementation of the Next Generation Air Transportation System. This will be possible from day one of the research, because many envisioned NGATS functions have already been prototyped and well integrated. Worldwide recognitions for research results obtained in the MACS/ADRS environment have demonstrated the high quality of the software functionalities. If this system will be used for FAA training it can save tax payers millions of dollars and facilitate new training platforms that will allow analysis and improvements to controller training on many levels beyond just replacing the hardware and the software.

Printed Name and Signature	*Title*	*Date*

3. TECHNICAL MANAGEMENT

I support/do not support a Space Act Award for this contribution for the following reasons.

Dr. Prevot and his MACS software system represent an excellent example of doing what only NASA can do. Dr. Prevot and his software team in building MACS did what many people thought was impossible. In a few years they build arguably the world’s best system for prototyping and real-time simulation and human in the loop testing of new concepts for managing air traffic. Numerous government, university and industry groups have recognized the benefits of using MACS and have requested copies of the software for their own research.

MACS and ADRS have demonstrated a remarkable reliability and performance in conducting large scale, complex experiments. They have been used extensively to connect and combine resources at multiple NASA Centers and simulation Facilities. The system supports educational projects and fosters Inter-Center and Inter-Agency collaboration on many different levels. Most of all the research accelerates the transformation of the air transportation system by providing high quality research results early-on.

Printed Name and Signature	*Title*	*Date*

4. COMMERCIALIZATION MANAGEMENT

I support/do not support a Space Act Award for this contribution for the following reasons.

Printed Name and Signature	Title	Date

TO BE COMPLETED BY AWARDS LIAISON OFFICE

5. IDENTIFICATION OF CONTRIBUTORS

Name, Employer, and Percent Contribution	Social Security Number	Home Address

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6. PATENT INFORMATION

Patent Applied for? Y/N Granted? Y/N	Serial Number or Patent Number
Application filed by: Government? Non-Government?	Date Filed or Granted
License Granted Y/N	Company Name:

7. EVALUATION NUMBER 1 2 3

8. BUSINESS ADDRESS OF CONTRIBUTORS IF OTHER THAN NASA EMPLOYEES

9. AWARD LIAISON OFFICER COMMENTS AND SIGNATURE

Printed Name and Signature	Comments	Date